High-Frequency Acoustics Of Ocean Sediments And Biot's Theory

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LONG-TERM GOAL

A physical model of high-frequency sound interaction with the seafloor including, penetration through the water-seafloor interface, propagation within and scattering from the seafloor, in support of MCM needs.

OBJECTIVES

Experimental study and hypotheses testing to determine the underlying physical processes governing (A) the penetration of sound into ocean sediments, particularly at shallow grazing angles, and (B) the scattering of sound from the sediment. Although a number of measurements have been made in the past, including both in-situ and laboratory experiments, and a number of hypotheses have been advanced, the underlying physical processes could not be determined with any confidence. The hypotheses may be roughly divided into two groups, one in which the sediment is approximated as an elastic fluid (e.g. Moe and Jackson 1998) or solid (e.g. Jackson and Ivakin 1998) and the other in which the sediment is treated as a poro-elastic medium (e.g. Chotiros 1998).

A. Penetration: There are two competing hypotheses for the penetration path at shallow grazing angles: (1) Biot slow wave refraction and (2) Scattering by surface and/or volume inhomogeneities. Within each there are a number of interconnected possibilities. The Biot slow wave path is applicable to a uniform sediment with a flat surface, but it may be enhanced by surface roughness and volume inhomogeneities through energy conversion between the slow and fast waves. The scattering path requires either surface roughness and/or volume inhomogeneities, but it is not known if the process may be adequately represented by an elastic medium approximation, or if it is necessary to resort to a Biot representation.

B. Scattering: At the most fundamental level, it is desirable to determine if the scattering process is single or multiple scattering. At the physical level, the scatterers need to be identified, and the likely candidates include (a) surface roughness, (b) volume inhomogeneities, and (c) the sand grains. The acoustic path by which the scatterers are insonified are covered under the penetration study. Tests are needed to distinguish between the different scattering mechanisms.

APPROACH

For best results, in-situ experimentation is required due to the near impossibility of reproducing realistic ocean sediment conditions in the laboratory, particularly the arrangement of grains under natural sediment deposition conditions, and the reworking of the sediment by various natural

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **High-Frequency Acoustics Of Ocean Sediments And Biot's Theory**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of of Texas at Austin,Applied Research Laboratories,Austin,TX,78713**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

processes. New measurement methods have been designed to eliminate the shortcomings in previous studies and provide the necessary discrimination between the candidate hypotheses. They are realized in an experiment involving (A) a mobile sound source carried on a remotely operated vehicle (ROV) and (B) tilted, rigidly supported, buried acoustic line arrays, as illustrated in Fig. 1, in combination with broadband signals and new signal processing methods.

A. A ROV as the platform for the sound source and backscatter receiver, provides several advantages that were previously unavailable. The vertical mobility provided by a ROV allows the buried array to be insonified over a continuous range of grazing angles. The dependence of bottom backscattering strength on height above bottom, which is an indicator of single or multiple scattering, may be studied. An ensemble of backscattering measurements from a large area, as a function of grazing angle and bearing, may be obtained with enough independent data points to construct a detailed frequency distribution curve. Although the ROV is constantly in motion, the position of the sound source, at each ping, may be accurately determined relative to the receiving array, by triangulation using time of flight measurements from the three hydrophones on the sediment surface.

B. Tilted buried line arrays, on rigid supports, are used instead of vertical buried line arrays of past experiments. The unit consists of a tilted line array, attached to a support frame resting on the sand surface, down range of the sound source. The tilted geometry was chosen because it has been argued that possible scattering artifacts at the water-sand interface caused by the insertion of vertical arrays could have produced the appearance of a refracted slow wave. In the tilted geometry, the sediment directly above the acoustic sensing elements is undisturbed, eliminating the possibility of scattering artifacts within a broad cone of angles. The array unit may be buried with minimal disturbance to the sediment. A small water jet at the tip, driven by a portable, battery-operated pump, liquefies a small volume of sediment directly ahead of the array and allows the unit to slip into the sediment. Only a small volume of sediment around the line array is disturbed by the action of the water jet. Preliminary tests in a sandy site indicated that it is feasible to bury rigid line arrays of up to 2 meters in length in this way. The improved positioning accuracy due to rigid supports allows coherent processing up to 200 kHz, which is an essential requirement for distinguishing between a refracted wave, which tends to be coherent, and scattered sound energy which is incoherent.

Broad band signals, made possible by new transducer materials, are used in order to detect frequency dependent trends in both penetration and scattering, which will provide important clues to the underlying physical mechanisms. Of particular interest are the attenuation, transmission and scattering coefficients as a function of frequency. Existing empirical models (Hamilton 1980) indicate that attenuation is linearly proportional to frequency, but older (Nolle et al. 1963) and more recent (Simpson and Houston 1996) laboratory experiments show significant deviations. On a practical level, broad band signals allow sparse arrays to be used in the estimation of direction and speed of coherent waves, and phase coherence across a broad band is a good indicator of a refracted wave, as opposed to a scattered wave.

Using a new inversion algorithm, the most difficult Biot parameters, i.e. grain bulk modulus, frame bulk and shear moduli, will be inverted from acoustic measurements. The measurements including reflection loss at normal incidence from Steve Schock, FAU, p- and s- wave speeds from Mike Richardson, NRL, along with the usual geo-acoustic measurements of porosity, density, and grain size from Kevin Briggs, NRL. The inversion is a non-linear one, but it has proved to be stable and rapidly convergent.

The frequency dependence of the Q-factor of the scattered signal will be computed as another independent indicator of single or multiple scattering. A Q-factor that is increasing with frequency is indicative of a multiple scattering process.

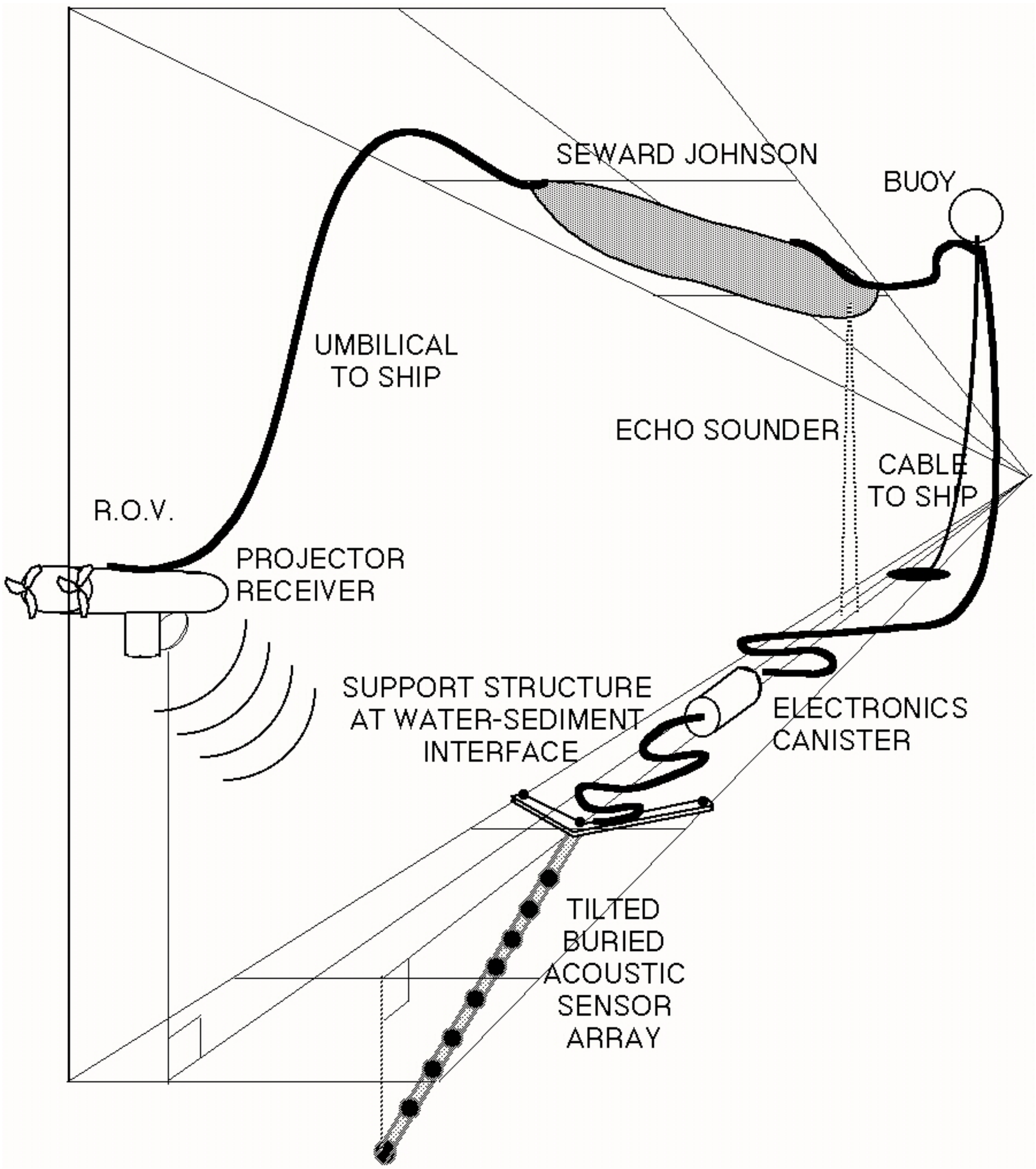

Figure 1. Illustration of experiment concept

WORK COMPLETED

Experiment planning was completed early in the fall of 1998. Design and construction of the broad-band projector and receiving arrays, electronic data collection equipment and cables were completed. Modifications were made to a ROV for specifically for this project. Software for the data collection system was written. Costs were minimized by adapting data collection hardware and software from a compact sonar system designed for divers and small ROVs currently being developed at ARLUT.

The equipment was tested in the ARLUT tank facility before deployment. The system was deployed at the SAX99 experiment in the designated site. Two buried arrays were deployed. A sound source on the ROV was used to insonify the buried receivers to measure penetration. A receiver on the ROV also measured backscatter. The experiment is still in progress.

RESULTS

Preliminary results indicated that good quality data were being collected. Signals were detected at the buried receivers at various grazing angles, both sub- and super- critical. Final results will be known after further analytical processes are applied to test the candidate theories using coherent processing methods.

IMPACT/APPLICATION

The results will generate new theoretical models that will be significantly superior to the current acoustic sediment interaction models, including bottom scattering and penetration, for all sonar models related to mine hunting.

TRANSITIONS

The models provide a theoretical frame work for analyzing bottom reverberation data currently being collected under NAVO sponsorship, and sonar performance predictions sponsored by ONR code 322.

RELATED PROJECTS

This project is tightly coupled to the other projects under the ONR “High-Frequency Sediment Acoustics” DRI, since the environmental inputs required for analysis are dependent on other projects within the DRI.

This project is related to the Acoustic Penetration Experiment (APEx) that was conducted in April 1999 by the SACLANTCEN, in Italy, on a similar sandy sediment in the Mediterranean, and currently being analyzed. Measurements and results will be exchanged at the appropriate times.

The results will be compared to the acoustic penetration measurements in the laboratory (Simpson and Houston 1996) at NRL/DC, to recent acoustic penetration and scattering measurements conducted in-situ, off Panama City, FL, by Steve Stanic, at NRL/SSC, and to measurements in laboratory conditions by Drevet, at the Laboratoire de Mecanique et d’Acoustique, France.

REFERENCES

Chotiros, Nicholas P. 1998: Biot's theory and granular media. Poromechanics- A tribute to Maurice A. Biot, J.-F. Thimus et al. (eds.), pp. 191-196, Balkema, Rotterdam.

Hamilton, E. L. 1980: Geoacoustic Modeling of the Sea Floor. J. Acoust. Soc. Am. 68, 1313-1340

Jackson, Darrell R. and Ivakin, A. N. 1998: Scattering from elastic sea beds: First-order theory. J. Acoust. Soc. Am. 103(1), 336-45

Moe, John E. and Jackson, Darrell R. 1998: Near-field scattering through and from a two-dimensional fluid–fluid rough interface. J. Acoust. Soc. Am. 103(1), 275-87

Nolle, A. W.; Hoyer, W. A.; Mifsud, J. F.; Runyan, W. R.; Ward, M. B. 1963: Acoustical properties of water- filled sands. J. Acoust. Soc. Am., 35(9), 1394-1408

Simpson, Harry J. and Houston, Brian H. 1996: Measurement of acoustic wave speeds in a fluid-saturated sandy bottom, J. Acoust. Soc. Am. 100(4), Pt. 2, 2766

PUBLICATIONS

Chotiros, Nicholas P. 1998: Acoustic penetration of a sandy shallow water sediment in the 500 to 1000 Hz band, Oceans'98 IEEE/OES Conference Proceedings, 98CH36259, vol. 1, pp.22-25, Nice, France, 28 September - 1 October 1998.

Chotiros, Nicholas P.; Yelton, Dennis J. and Stern, Morris 1999: An acoustic model of a laminar sand bed. J. Acoust. Soc. Am. 106(4), Pt. 1, 1681 - 1693

Chotiros, Nicholas P. 1999: Acoustic inversion for Biot parameters in water saturated sand, . J. Acoust. Soc. Am. 105(2), Pt. 2, 1265

Chotiros, Nicholas P. in press: Geophysical parameters in a poro-elastic sediment. Proc. Experimental Acoustic Inversion Workshop 99, ed. Andrea Caiti, Carvoeiro, Portugal, 22 - 24 March 1999

Richardson, Michael D.; Wood, Warren D.; Jans, Wolfgang; Fleischer, Peter; Briggs, Kevin B.; Lavoie, Dawn L.; Lott, Daniel F.; Lambert, Douglas N.; Lindwald, Dennis; Walter, Donald J.; Griffin, Sean; Smith, D. Eric 1999: Recent advances in acoustic sediment classification. J. Acoust. Soc. Am. 105(2), Pt. 2, 1207

Wood, Warren D.; Jans, Wolfgang; Smith, D. Eric 1999: Effects of differing sediment types and structures on normal incident acoustic reflections. J. Acoust. Soc. Am. 105(2), Pt. 2, 1264